Vortex pinning study on epitaxial YBa$_2$Cu$_3$O$_{7-x}$ thin film grown on decorated MgO(001) single crystal substrates with La$_{0.66}$Sr$_{0.33}$MnO$_3$ nano-islands

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Abstract

In the present paper we investigate the influence of La$_{0.66}$Sr$_{0.33}$MnO$_3$ (LSMO) nanostructures on the transport and magnetic properties of YBa$_2$Cu$_3$O$_{7-x}$ (YBCO) thin films. The LSMO nanostructures were obtained by polymer assisted deposition (PAD). The polymer assisted deposition technique is a promising alternative for the deposition of buffer layers for high temperature superconducting thin films, in coated conductor applications. By choosing the appropriate deposition conditions nano-islands having a mean diameter of 20 nm were grown on MgO (001) single crystal substrates, with a highly uniform substrate coverage. Their density was 500 μm$^{-2}$. No short length ordering of the particles was observed. The as-obtained surface decorated substrates were used as templates for the subsequent growth of YBCO films. The superconducting layers were grown by co-evaporation. The aim of the study is to characterize the pinning landscape produced by the nanostructures. An increased critical current density and pinning force was recorded for the YBCO film deposited on the as-decorated substrates in all measured field and temperature ranges. However, a detailed analysis of the pinning force density, close to the critical transition temperature, revealed that a single pinning mechanism is present in both the YBCO film and the one deposited on the LSMO decorated substrate. Taking into account the TEM and XRD analyses, we ascribe the enhanced superconducting properties to the structural defects induced in the YBCO film by the LSMO nano-islands. No magnetic pinning contribution was observed, as expected due to the ferromagnetic nature of LSMO.

Morphological properties of LSMO nanoparticles obtained by PAD

- Polymer Assisted Deposition (PAD) of La$_{0.66}$Sr$_{0.33}$MnO$_3$ (LSMO) nanostructures on MgO (001) single crystal substrates
  - Solution concentration (nanoparticle density): C = 0.001 M (200 μm$^{-2}$)
  - C = 0.01 M (500 μm$^{-2}$)
- Nanostructure densities appear to saturate above C = 0.005 M to approximately 500 μm$^{-2}$;

Mean LSMO dot diameter was found to be 27 ± 11 nm
- Average nano-dot height is approx. 10 nm
- Nano-dots were epitaxially grown on the MgO substrates with the epitaxial relationship: (001)LSMO||(001)MgO and (110)LSMO||(110)MgO

Superconducting transport properties of YBCO and LSMO/YBCO thin films

- Sample | Te (K) | Jc (MA/cm$^2$) @ 77 K, 0 T |
<table>
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<tr>
<td>YBCO</td>
<td>83.9</td>
<td>1.1</td>
</tr>
<tr>
<td>LSMO/YBCO</td>
<td>84.1</td>
<td>1.4</td>
</tr>
</tbody>
</table>

| Matching field, $B_m$: YBCO – 0.6 T, LSMO/YBCO – 1 T |

Pinning site density: YBCO $\sim$ 300 μm$^{-2}$ - LSMO/YBCO $\sim$ 500 μm$^{-2}$ (good agreement with LSMO dot density)

Pinning population investigation in YBCO and LSMO/YBCO thin films

- No clear indication of the presence of an additional (magnetic) pinning mechanism was observed in the LSMO/YBCO film

Conclusions

- LSMO nanoparticles having a mean diameter of 25 nm and a surface density of $\sim$ 500 μm$^{-2}$ were obtained by the PAD method.
- Improved transport properties of the YBCO film deposited on the LSMO decorated MgO (001) substrate in all temperature and field ranges;
- No clear indication of an additional (magnetic) pinning mechanism LSMO/YBCO; Influences of the grain boundaries on the pinning properties of the LSMO/YBCO structure is assumed to be responsible for the improved superconducting transport characteristics.

Acknowledgements

This work was supported by a Grant of the Romanian National Authority for Scientific Research CNCS – UEFISCUD, Project number PN-II-PU-TE-2014-4-2848, MAGPIN. Also, this work has been carried out within the framework of the EUROfusion Consortium and has been received funding from the European Union’s Horizon 2020 research innovation programme under grant agreement number 633053 and also from the Romanian National Education Minister under contract 1EU/2014. The reviews and opinion expressed herein do not necessarily reflect those of the European Commission.

Field angle critical current density dependence

- Improved critical current densities were observed in the case of the LSMO/YBCO in all temperature, angle, and field ranges;
- Similar features were observed in both samples suggesting a common pinning origin.